PATENT SPECIFICATION

DRAWINGS ATTACHED

990,699

990,699

Date of Application and filing Complete Specification Feb. 5, 1963.
No. 4604/63.
Application made in France (No. 886980) on Feb. 5, 1962.
Application made in France (No. 916814) on Nov. 28, 1962.
Complete Specification Published April 28, 1965.
© *Crown Copyright 1965.*

Index at acceptance: —H2 A(1A, 1C7A, 1C8, 16N, 16P)
Int. Cl.:—H 02 k

COMPLETE SPECIFICATION

Improvements relating to Variable Reluctance Electrical Machinery

We, JEAN JARRET, of "La Champanelle", Chemin du Clos Baron, Fourqueux, France, and JACQUES JARRET, of 35 bis, avenue du Belloy, Le Vesinet, France, both of French Nationality, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to dynamo electrical machines and more particularly to electric machines of the type disclosed by the same Applicants in British Specification No. 940,233.

This Specification relates to variable-reluctance electrical machinery having the main feature that the mean saturation induction of the rotor teeth is reduced to some 15 to 85% of the maximum induction chosen for the magnetic circuit of the machine in order that relatively strong magnetic fields may be used in the main air gaps without excessive losses, so that the machinery has a high power-to-weight ratio. To this end, the rotor are formed by alternate magnetic and non-magnetic layers, for instance, pure iron laminations separated by layers of air.

In one embodiment of the aforesaid patent specification the stator comprises at least two identical pole pairs, each pole having an angular span or width a and the space between consecutive poles having an angular extent b, and the moving part comprises teeth having an angular extent of substantially $a+b$. When a machine of this kind which has two pairs of poles is used as an alternator, each pole is magnetised through the agency of at least one winding, one end of which is supplied with exciting d.c. while the other end is connected to a line through which flows the a.c. produced by the alternator, the ends of two contiguous windings being interconnected and arranged as a bridge circuit so that the exciting d.c. is supplied via one shunt arm of the bridge and the a.c. passes through the other shunt arm. Consequently, the flux variations which are produced in two consecutive poles by a tooth of the moving part moving past such poles are always equal and opposite, and so, since the voltage induced at the two ends of the d.c. shunt arm is always substantially the same, only a low unwanted a.c. flows in the alternator excitation line; also, since the a.c. voltages induced at the two ends of the a.c. shunt arm always vary oppositely, all the mechanical energy supplied to the alternator rotor is in theory converted into useful electric current, less normal iron and copper losses.

It has been found that this embodiment, however, that perfect separation between the magnetic circuits of the two pole pairs is impossible, and so the ideal conditions just outlined cannot be approached closely enough for optimum efficiency of the machine.

It is an object of the present invention to improve the efficiency and range of uses of electrical machines having the main feature of the aforesaid patent specification. A feature of this invention is separation of the magnetic circuits of consecutive stator poles, and a corresponding division of the rotor into two parts rigidly secured to one another.

According to the invention, the rotor is divided perpendicularly to its axis into two half-rotors rigidly interconnected to one another, and the stator is divided into two half-stators, each of which corresponds to a half-rotor and comprises at least one pole pair opposite the corresponding half-rotor; all the poles of each half-stator have the same width and each half-stator pole has a winding, one end of which is connected to the winding of the pole of the same pair, while

the other end is connected to the winding of a pole of the other half-stator; and each half-rotor has as many toothed pairs as each half-stator has pole pairs, each tooth having substantially the same width as each pole, the relative arrangement of the poles and of the teeth being such that the sum of the angles of that part of a tooth of the first half-rotor which is opposite a particular pole, and of that part of a tooth of the second half-rotor which is opposite a pole whose winding is connected to one end of the penultimately mentioned pole, is always equal to the width of each individual pole.

According to another feature of the invention, in machines having two pole pairs, the teeth of the second half-rotor can be staggered by $\pi/2$ relatively to the teeth of the first half-rotor, in which event the pole pairs are parallel with one another; the stator can then be produced from oriented-grain laminations, with a consequent improvement in the power-to-weight ratio.

An advantage of an electrical machine having two pole pairs according to the invention when used as an alternator in which the points common to the windings of each pole pair are respectively connected to a d.c. exciting source and the a.c. produced by the alternator is delivered between the places common to the other ends of the last-mentioned windings, as set forth in the aforesaid patent application, is that the current which the a.c. circuit can provide is limited to the current delivered by the exciting source because of the demagnetising ampere turns of the output a.c.; in the event of the a.c. output being short-circuited, the demagnetising ampere-turns just mentioned become equal to the magnetising ampere-turns of the exciting circuit, and so it is impossible to overload the alternator.

One particular advantage of an alternator according to the invention is the readiness with which it can be regulated, for a slight variation in exciting current can produce a large variation in output. More particularly where a component of the exciting current is proportional to the output current, effective regulation can be provided by variation of a small external current. Another advantage of electrical machines according to the invention is that, since the exciting windings are connected in series, the machine can operate as a universal motor if the exciting windings are short-circuited alternately in synchronism with motor rotation, overvoltages being reduced considerably by the inductance of the winding in series with the shortcircuited winding.

In the aforesaid patent specification, the magnetic characteristics of the teeth of the moving part are constant throughout their width. More particularly, in the embodiment of an alternator described in such patent application, where the rotor teeth have a substantially parallelepipedic shape, like the stator poles past which the rotor teeth move, they increase in magnetic flux when a tooth starts to pass a pole, and the decrease in magnetic flux when a tooth starts to leave a pole, are constant and proportional to the angular displacement of the rotor; consequently, the voltages produced in the stator windings as a tooth passes a pole have consecutively two opposite and substantially constant values at least during low-load or no-load operation. The output from an alternator of this kind operating under these conditions is substantially rectangular, a factor which may be disadvantageous for supplying some networks or where the machine is required to operate as a synchronous motor on a supply providing a sinusoidal current.

It is an object of the invention to obviate this disadvantage.

A feature of the electrical machine according to one particular embodiment of this invention is that their teeth are so devised that their mean density of magnetic metal decreases substantially sinusoiadlly on either side of the tooth axis. In one particular embodiment of variable-reluctance electrical machines according to this invention, each rotor tooth is formed by substantially rectangular profile laminations having an angular span less than the angular span of the stator poles and more than half the last-mentioned angular span, the rotor tooth laminations being staggered fanwise so that together they have the same angular span as the stator poles or a slightly smaller angular span, so that the mean density of magnetic material is greater near the tooth axis—where such density corresponds to the sum of the thicknesses of the laminations forming the tooth for a given thickness of dielectric, for instance, air—and decreases stepwise to a minimum at the tooth ends.

This feature, which enables the voltage induced in the stator windings to be varied in accordance with any desired pattern, more particularly sinusoidally, is of use not only in alternators and synchronous motors but also in d.c. motors in which the stator windings are switched in synchronism with rotor rotation, for the use of teeth according to the feature just described on two rotors angularly offset from one another by half a tooth evens out the torque and improves the conditions for synchronous switching.

For a better understanding of the invention and to show how the same may be carried into effect, reference may now be made to the accompanying drawings wherein:

Fig. 1 diagrammatically illustrates in axial section a four-pole electrical machine according to the invention in alternator form;

Fig. 2 is a perspective view of the machine illustrated in Fig. 1, in section along the

line II—II of Fig. 1 and with one-quarter of the stator removed to show the rotor;

Fig. 3 diagrammatically illustrates the arrangement of a rotor tooth of a machine according to one particular embodiment of the invention, and

Fig. 4 is a perspective view similar to Fig. 2 with the rotor teeth devised similarly to the arrangement shown in Fig. 3.

Referring to Figs. 1 and 2, a stator 31 of alternator of the type having an unwound toothed rotor comprises a group of magnetic laminations 32 which can be of the oriented-grain kind, and has four identical poles 33*a*, 33*b*, 33*c*, 33*d* having an angular span $\pi/2$. Pole 33*a* is in alignment with pole 33*d*, and pole 33*b* is in alignment with pole 33*c*; pole 33*b* is opposite pole 33*a*, and pole 33*c* is opposite pole 33*d*. Each pole has a winding 34*a*, 34*b*, 34*c*, 34*d*; the four windings are are identical and can withstand the alternator excitation current and the a.c. output together.

The moving part or rotor comprises two parts or half-rotors 38_1, 38_2 disposed on a single shaft 39. Each half rotor 38_1, 38_2 is formed in the fashion set forth in the aforesaid patent specification—i.e., by a group of magnetic laminations 28*a*, 30*a*; in two diametrically opposite segments extending over approximately $\pi/2$, the laminations 28*a* have a diameter greater than the diameter of the laminations 30*a* so that there are air spaces 29*a* between those parts of the laminations 28*a* which extend beyond the laminations 30*a*. These extending parts of the laminations 28*a* are aligned on each half-rotor to form teeth 40_{a1} and 40_{b1} of the half-rotor 38_1 and teeth 40_{a2} and 40_{b2} of the half-rotor 38_2. The teeth 40_{a1}, 40_{b1} of the half-rotor 38_1 are staggered by $\pi/2$ relatively to the teeth 40_{a2}, 40_{b2} of the half-rotor 38_2. Consequently, the sum of the opening angles of those parts of the teeth 40_{a1}, 40_{a2} and of the teeth 40_{a2}, 40_{b2} which are at any time associated with a pole is constant and equal to $\pi/2$. As the rotor rotates, the magnetic flux variations produced in the poles 33*d* and 33*a* are therefore always equal and opposite, as are the flux variations which are simultaneously produced in the poles 33*c*, 33*b*. The voltages induced by these flux variations in the respective windings 34*a*, 34*b* and 34*c*, 34*d* are therefore always equal and opposite.

When a bridge circuit arrangement I, J, K, L is used as shown in Fig. 1 where the windings 34*a*, 34*b* are connected in parallel to one terminal of an excitation source 37 and in series with the windings 34*d*, 34*c* which are connected in parallel to the other terminal of the source 37 and the alternator output is taken from the place L common to the windings 34*a*, 34*d* and from thte place J common to the windings 34*b*, 34*c*, it will be apparent that, since the voltages induced at the ends of the bridge shunt arm I—K are always equal and of the same sign, no a.c. reaches the excitation line; also, since the voltages induced at the ends of the shunt arm J—L are equal and of opposite phase, all the mechanical energy supplied to the rotor 38 is transduced to the output line in the form of a.c., less normal iron and copper losses. This result, which depends, of course, upon the teeth of the rotor 38 being saturated while the other parts of the alternator are not saturated, is helped by the separation between the magnetic circuits of the poles which experience flux variations in opposite directions.

Fig. 3 illustrates by way of non-limitative example, in plan and in elevation, a tooth of a rotor 40, such tooth being formed by four identical and coaxial groups *a*, *b*, *c*, *d* each comprising four pure iron laminations, as 42*a*, 43*a*, 44*a*, 45*a* which are staggered relatively to one another by an equal amount equal to one-fifth of their length so that each group, and therefore the tooth, have a length equal to eight-fifths of the length of each lamination. The laminations, as 42*a*, are substantially rectangular extensions, of height *h*, of pure iron laminations forming, together with circular laminations 45 which separate from one another and frame the groups *a*, *b*, *c*, *d*, the complete rotor 40, only some of which is illustrated.

Along the tooth axis—i.e., at the place where the passage past a pole is required to give the greatest variation in reluctance flux—the mean density of metal corresponds substantially to four thicknesses of iron for a single thickness of air layer separating the groups—i.e., to 4/5. Between one-eighth and two-eights of tooth length on either side of its axis, the mean density of metal corresponds to three thicknesses of iron for two thicknesses of air layer—i.e., to 3/5, between two-eighths and three-eighths to 2/5, and between three-eighths and four-eighths to 1/5. In other words, this variation of the mean density of magnetic metal along tooth length, and the corresponding variation in saturation induction, are substantially sinusoidal.

Fig. 4 differs from Fig. 2 only in the details of rotor construction, which is as illustrated in Fig. 3. Fig. 4 shows how a tooth is formed by fanwise-staggered extensions, as 41*a*, 42*a*, 43*a*, 44*a*, of groups of four laminations forming four elements *a*, *b*, *c*, *d* of a rotor tooth and framed and separated by circular laminations, as 45.

WHAT WE CLAIM IS:—

1. An electrical machine of the type having an unwound toothed rotor and in which a stator has at least two pairs of electromagnetic poles and a rotor has at least two pairs of teeth formed by thin iron laminations separated from one another by non-

magnetic zones, for instance, of air, wherein the rotor is divided perpendicularly to its axis into two half-rotors rigidly secured to one another, each such half-rotor comprising at least one pair of teeth, and the stator is divided into two half-stators, each of which corresponds to one half-rotor and comprises at least one pair of poles opposite the rotor.

2. A machine as set forth in claim 1 wherein all the poles of each half-stator have the same angular span and each half-stator pole has a winding, one end of which is connected to the winding of the pole of the same pair, while the other end is connected to the winding of a pole of the other half-stator.

3. A machine as set forth in claim 2 wherein each half-rotor has as many tooth pairs as each half-stator has pole pairs, each tooth having substantially the same angular span as each pole, the relative arrangement of the poles and of the teeth being such that the sum of the angles of that part of a tooth of the first half-rotor which is opposite a particular pole, and of that part of a tooth of the second half-rotor which is opposite a pole whose winding is connected to one end of the penultimately mentioned pole, is always equal to the angular span of each individual pole.

4. A machine as set forth in claim 3 wherein each half-stator comprises a pair of poles and each half-rotor comprises a pair of teeth and the teeth of each half-rotor are staggered by $\pi/2$ relatively to the teeth of the other half rotor, and the stator pole pairs are parallel with one another.

5. A machine as set forth in claim 4 wherein each half-stator is formed by oriented-grain laminations.

6. A machine as set forth in claim 1 wherein the rotor teeth are so devised that their mean density of magnetic metal decreases substantially sinusoidally on either side of their axis.

7. A machine as set forth in claim 6 wherein each rotor tooth is formed of substantially rectangular profile laminations having an angular span less than the angular span of the stator poles and more than half the last-mentioned angular span, the rotor tooth laminations being staggered fanwise so that together they have the same angular span as the stator poles or a slightly smaller angular span, so that the mean density of magnetic material is greatest near the tooth axis—where such density corresponds to the sum of the thicknesses of the laminations forming the tooth for a given thickness of dielectric, for instance, air—and decreases stepwise to a minimum at the tooth ends.

8. An electrical machine substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

FORRESTER, KETLEY & CO.,
Chartered Patent Agents,
Jessel Chambers, 88—90, Chancery Lane,
London, W.C.2, and
Central House, 75, New Street,
Birmingham, 2,
Agents for the Applicants.

Leamington Spa: Printed for Her Majesty's Stationery Office by the Courier Press.—1965.
Published at The Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies may be obtained

990699 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

FIG.1

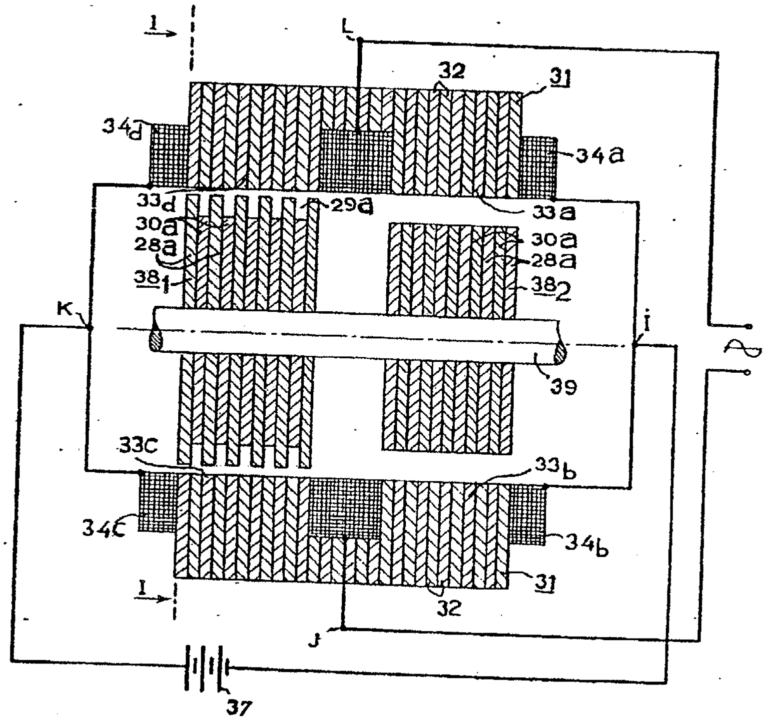
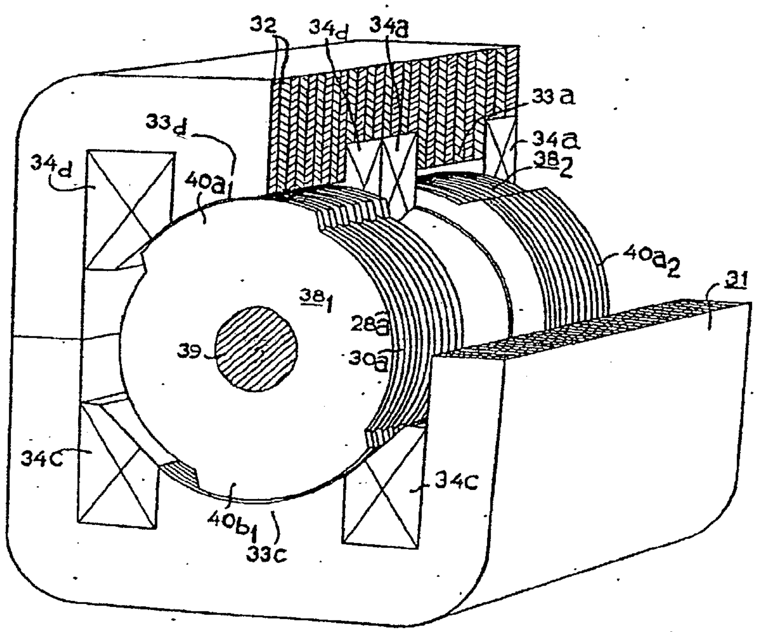


FIG.2



32
34d
34a
33a
33d
34a
34d
40a1
38 2
40a2
31
38 1
28a
39
30a
34c
34c
40b1
33c

990699 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheets 2 & 3

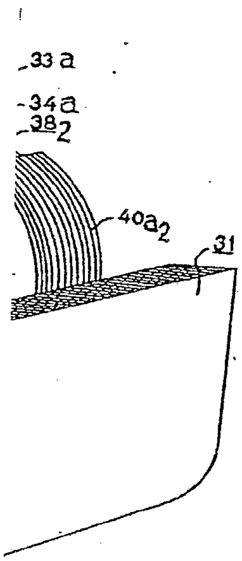


FIG. 3

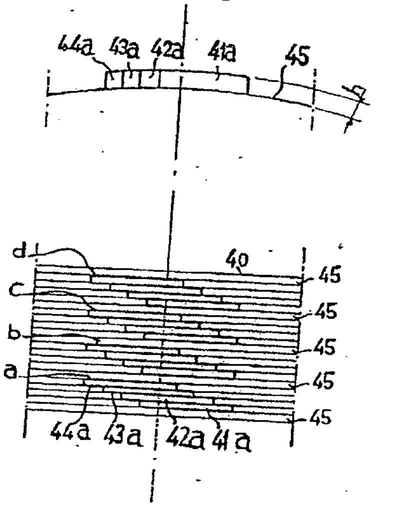
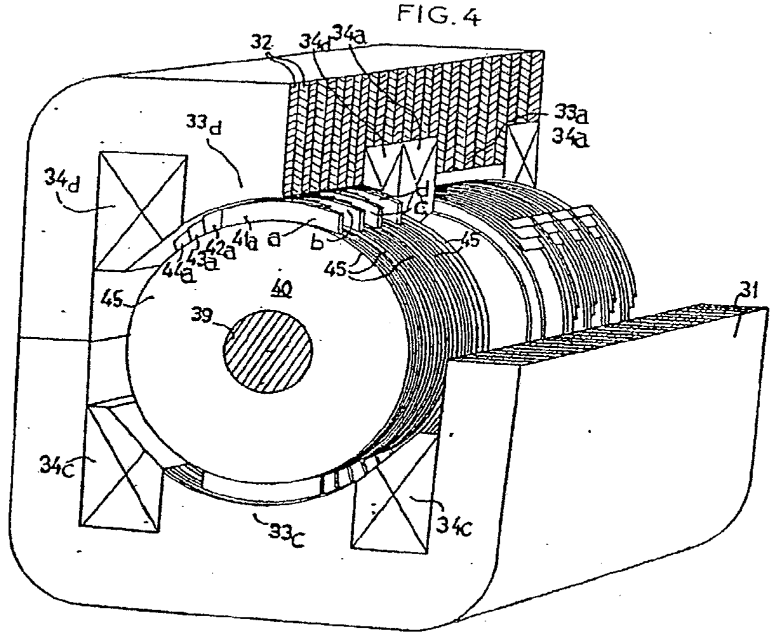


FIG. 4



990699 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheets 2 & 3

FIG.3

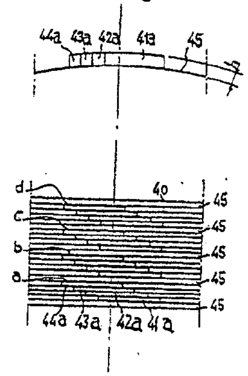


FIG.2

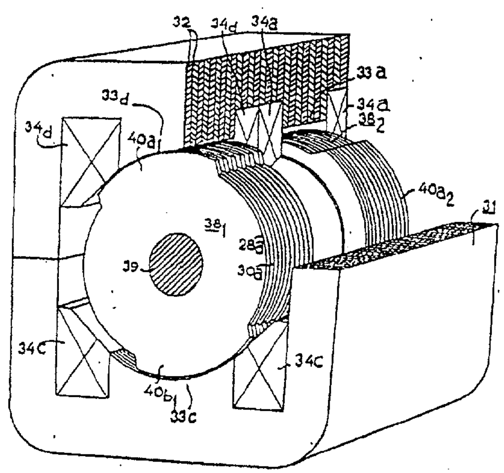


FIG.4